PATENT SPECIFICATION

605,734

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Index at acceptance:—Classes 37, A14; 40(iv), K9f; and 40(v), L6p.

COMPLETE SPECIFICATION

Improvements in or relating to High-frequency Detecting and Power Measuring Systems

We, JAMES GARRETT YATES and ROWLAND CLIVE ROBBINS, British subjects, both of the Ministry of Supply, London, and TORLEIF PEDER HVINDEN, a Norwegian subject of Lunner St. Hadeland, Norway, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

This invention relates to high-frequency detecting and power-measuring systems of the kind utilising a directly-heated resistance element having a characteristic independent of frequency to such extent that D.C. or relatively low-frequency power measurements are indicative of H.F. power dissipation.

In this specification the word "detecting" when applied to high-frequency currents means indicating the incidence of high frequency current and does not mean rectifying the high-frequency currents to reveal amplitude modulation. The word "low-frequency" means a frequency much lower than that of the high-frequency current to be detected or measured.

One type of resistance element which is commonly used is the hot filament or bolometer resistance, sometimes in the form of a filament lamp, designed to have a power-resistance characteristic substantially independent of frequency. Another type, with which the present invention is more particularly concerned, is the directly-heated thermistor bead, which is a very small bead bridging two connecting wires, the material of the bead being a metal oxide or other semi-conductor having a large negative temperature coefficient of resistance. The bead may be mounted in a small glass tube of the order of one centimetre in length, with the connecting wires sealed in the ends of the tube. Alternatively a cartridge as disclosed in copending application No. 33973/45 (Serial No. 604,496) may be employed. Air filling at normal pressures may be used. These resistance elements are designed for coupling to H.F. sources with small loss.

With such frequency-independent resistance elements, H.F. power is evaluated by measuring the D.C. power or the D.C. power change necessary to give the same effect as, or to nullify the the effect of, the H.F. power.

When a frequency-independent non-linear resistance element terminating a co-axial line is to be inserted in a D.C. or low-frequency circuit, a conductive connection to the inner conductor of the co-axial pair has to be provided without introducing losses or reflections in the H.F. co-axial circuit. For short-wave co-axial circuits, the conductive connection may be made over stubs of such length as to avoid reflection suitably disposed along the co-axial line and for longer-wave circuits conductive connection through choke coils may be made, the co-axial line including capacitative joints in each case to provide the necessary D.C. or L.F. insulation. Tuned stubs or chokes however, tend to limit the frequency range of operation and rematching on change of frequency is usually necessary.

An object of the present invention is to avoid this disadvantage.

In one aspect the invention resides in a high-frequency detector comprising two thermistor or like non-linear resistance elements connected in parallel across a co-axial line for H.F. energy and in series in a D.C. or low-frequency circuit.

The resistance elements may be arranged in conductive series connection between capacitatively-coupled parts of the outer conductor of a co-axial plug or socket, the junction between the elements being connected to the inner conductor of the plug or socket.

[Price 1/-]

Price 4s 6d

In another aspect of the invention a high-frequency wattmeter comprises a D.C. or relatively low-frequency bridge circuit one arm of which is constituted by two thermistor or like non-linear resistance elements, said elements being arranged to be fed in parallel with H.F. energy by means of a co-axial line.

The bridge elements are preferably arranged in the manner hereinafter described to provide compensation for change in ambient temperature.

A portable, direct-reading, high-frequency milliwattmeter embodying the invention will now be described with reference to the accompanying drawings. The milliwattmeter shows full-scale deflection of one milliwatt of H.F. power, the input is matched to a seventy-ohm co-axial line with a voltage standing-wave-ratio better than about 1.2 over wavelength ranges of 40 to 100 centimetres and nine to eleven centimetres; compensation is provided for sensitivity variations and for zero drift due to variations of ambient temperature; calibration is effected by substituting D.C. for R.F. power.

The wattmeter essentially comprises a D.C. bridge circuit of which one arm consists of two thermistors in series. The latter are, however, in parallel with one another for the R.F. input as shown in Fig. 1 in which T1 T2 represent the thermistors and L the co-axial line. The fundamental bridge circuit is shown in Fig. 2 and comprises bridge arms R1, R2, R3 and the two thermistors T1, T2 in series, a galvanometer of resistane RG being connected across the bridge as shown. It is necessary that the voltage applied to the bridge should be adjustable in order that the temperature and hence resistance of the thermistors T1 and T2 should be maintained at such a value as to balance the bridge at any ambient temperature. For this purpose a series resistance R10 and shunt adjustable resistance R11, as shown in Fig. 2 may be employed. However, in order to minimize the necessary battery voltage, the fundamental circuit is preferably rearranged as shown in Fig. 3. Moreover, stability of balance is assisted by additional thermistors D1 and D2 as indicated in Fig. 4, which shows the details of the practical circuit. The values of the components throughout are determined to secure the features set out above.

A practical mechanical construction of the unit of Fig. 1, is shown in Fig. 5.

Referring to Fig. 5, the two bead thermistor elements T1 and T2 are disposed and series connected between two plates 1 and 2 capacitatively coupled and mechanically fixed to opposite sides of a brass block 3. The block 3 is bored to take a co-axial socket 4 and to form an extension of the outer tubular conductor of the co-axial socket. The socket 4 is of standard form comprising an axial conductor 5 supported by a distrene disc 6. The junction between the thermistor elements is connected to the axial conductor. Two auxiliary thermistor elements D1 and D2 of disc form are clamped over the opening in the end of the block by an end plate 7 of insulating material so that they are subject to substantially the same ambient temperature as the elements T1 and T2. These elements D1, D2 are insulated from block 3 by an insulating annulus 8 and have connecting wires, one of which is shown at 9, leading out from their centres at 10 and 11.

If the socket is coupled to a co-axial line of 70 ohms characteristic impedance coupled in turn to an R.F. source matched to the line, and if each of the two thermistor bead elements T1 and T2 has a working resistance adjustable in the neighbourhood of 140 ohms and is arranged as a terminating resistance in accordance with known principles and as described, then for a wide-band of frequencies for which the effective R.F. resistance differs but slightly from the D.C. working resistance the co-axial line may be correctly terminated in a resistance equal to its characteristic impedance by adjusting the D.C. working resistance and a D.C. output circuit is provided consisting of a resistance of about 280 ohms made up of the two thermistor bead elements in series. This output resistance due to its pronounced thermal characteristic varies in dependency upon the R.F. energy fed along the co-axial line.

The R.F. power which may be measured by resistance change in the output circuit is limited by the necessity of maintaining a sensibly matched terminal impedance for the co-axial line For a resistance variation of the order of 10% the matching remains sufficiently close to prevent serious power loss by reflection. The working resistance of the thermistor bead elements is adjustable by varying the standing current through them and an optimum value of working resistance may be found for which the matching is usefully maintained over a desired range of powers and a desired frequency band.

In a particular case using the thermistor mount described, with the thermistor bead elements working at a combined D.C. series resistance value of 300 ohms, a voltage-standing-wave-ratio (V.S.W.R.) of less than 1.22 was obtained over a wave-band of 40 to 100 centi-

metres. This means that the power loss due to mismatch and consequent reflection of the R.F. energy was less than one per cent. throughout the band. Furthermore no difficulty arises in maintaining this degree of matching for lower frequencies.

Hence the arrangement is highly suitable for comparing powers of widely differing frequency.

The effective R.F. resistance of the termination comprising the bead elements becomes less closely related to the D.C. working resistance as the frequency is increased. When the wavelength is comparable to the dimensions of the terminating resistance, the latter is no longer equivalent to a resistance uniformly distributed around the axial conductor. Efficient matching over a smaller wave-band can, however, still be obtained by suitable choice of the shape and dimensions of the ends of the co-axial conductors, of the disposition of the thermistor elements and of their working resistance.

The co-axial mount shown in Fig. 5, having useful characteristics at wavelengths longer than 40 cms. as already described, also gives a broad-band frequency response in shorter wavelength regions if the working resistance is suitably modified. In a particular case and for 10 cm. wavelengths, the optimum D.C. resistance value for the two thermistor elements in series was found to be about 500 ohms when the co-axial mount was coupled to a co-axial line of 71 ohms characteristic impedance. Over a wave-band of 8.8 to 11.0 cms., the power loss due to mismatch was then less than one per cent., the V.S.W.R. having a minimum value of 1.03 at a resistance value of 470 ohms. The mount was employed in the bridge to be described and the resistance variation was from 500 ohms at bridge balance to 450 ohms at full-scale deflection of the balance-indicating meter so that the matching was practically maintained for all useful bridge conditions.

Further reference will now be made to the bridge circuits of Figs. 2, 3 and 4, firstly in regard to sensitivity compensation.

For a D.C. bridge with given circuit-elements the galvanometer current dIg depends upon the unbalance dR in one arm R and upon the voltage E across R (see Fig. 2).

$$dIg = G.E.dR \quad \ldots\ldots (1)$$

where G = a constant depending upon the bridge circuit. In a thermistor-bridge overall sensitivity is defined by:

$$S = \frac{dIg}{dW_{R.F}} = G.E.\frac{dR}{dW_{R.F}} \quad \ldots\ldots (2)$$

where $dW_{R.F.}$ = a small amount of R.F. power applied to the thermistors.

In a direct reading bridge S must be constant whatever the operating conditions. When R is the resistance of a thermistor, E has to be varied to keep R at the same value when working at various ambient temperatures.

Relation (2) shows that if S is to be kept constant while E is varied, $\frac{dR}{dW_{R.F.}}$, has to be varied too. The change dR of a thermistor resistance R depends upon the total change dW of power dissipated in R, since $\frac{dR}{dW}$ is constant at varying ambient temperature when R is kept at the same value.

When an amount $dW_{R.F.}$ of R.F. power is applied to the thermistor there will be a change of resistance dR. The total change dW of power in R will consist of the applied R.F. power $dW_{R.F.}$ plus the change $dW_{D.C.}$ of D.C. power in R resulting from the change dR in resistance, that is to say,

$$dW = dW_{R.F.} + dW_{D.C.} \quad \ldots\ldots (3)$$

whence

$$\frac{dW_{R.F.}}{dR} = \frac{dW}{dR} - \frac{dW_{D.C.}}{dR} \quad \ldots\ldots (4)$$

The bridge circuit of Fig. 2 may be considered as thermistors of resistance R subject to E volts in series with a resistance Rs and a source of E M F of E_1 volts as shown in Fig. 2A. Then $\frac{dW_{D.C.}}{dR}$ will depend upon R_s and upon the initial D.C. power dissipated in R. Fig. 2A shows that to vary E, R_s has to be varied E_1 being constant.

Thus a variation of E will cause a variation of $\frac{dW_{R.F.}}{dR}$.

A circuit wherein the variation of $\frac{dR}{dW_{R.F.}}$ approximately compensates for variation of E has a bridge-sensitivity S nearly constant over a wide range of ambient temperature. Fig. 2 is such a circuit but it can be shown that to give good compensation R_s of Fig. 2A must be large. That means that the circuit will need a high battery voltage, and yet give

low bridge-sensitivity. To give high bridge-sensitivity at low battery voltage the circuit in Fig. 3 is preferred. For a given battery voltage, curves showing variation of sensitivity with ambient temperature may be theoretically derived. The curve for $E_o = 12$ volts is experimentally verified from 15 to 40° C. Without compensation the error in overall sensitivity would be about +9% at 0° C. and −9% at 40° C. The improvement on this amounts to a factor of about 2, higher factors being attainable with higher battery voltages.

The considerations as to zero drift are as follows.

When the bridge in Fig. 3 is balanced at a certain ambient temperature, and this temperature then changes, the bridge will go out of balance. To rebalance, the D.C. power in R must be varied by varying R_o. If R_o is the resistance of a suitable network containing a disc-thermistor, the temperature-change itself can be made to give the right variation of R_o, and the bridge will remain balanced.

Hence the detailed circuit of Fig. 4 is reached. In this figure a battery of six portable secondary cells of lead type operating between 12.5 and 11.5 volts is represented at E_o. The bridge proper comprises equal resistances R2, R3 and equal resistances R4, R5, the two thermistor bead elements T1 and T2 and a resistance R1 approximately equal to the combined resistance of T1 and T2, all these elements corresponding to those of Fig. 3, with resistance values marked for a specific case. The balance indicating galvanometer G is a microammeter connected to a trimming potentiometer VR1 inserted between resistances R2, R3. A preset resistance VR2 is inserted in the galvanometer connection to provide for direct power reading and a switch S and a resistance R7 provide for calibration and use of the galvanometer as a voltmeter.

One or more disc thermistor elements D1, D2 shunted by a preset resistance VR4 are connected in series with a variable resistance VR3 for zero adjustment across the arms R, R1 of the bridge.

The bridge is set up in the following manner.

With R and R1 shorted, and switch S in position 2, VR1 is adjusted until the bridge is balanced.

With the switch in position 1 E_o is separately measured in order to calibrate the microammeter G for use as voltmeter. Readings are taken of the microammeter corresponding to the value of E_o indicated by a reference voltmeter connected directly across the battery.

With E_o equal to 12.0 volts and an ambient temperature of 25° C., and the switch in position 2, the zero-set resistance VR3 is adjusted to the middle of its range and the bridge is balanced by means of VR4. The value of R1 is measured accurately (e.g. by a P.O. Box) and this value used in the manner disclosed in Specification No. 588,903 to evaluate the D.C. power in R from the expression $W_{D.C.} = \frac{E_B^2}{4.R1}$ where E_B = voltage across R and R1.

For calibration, the bridge is balanced and the voltage E_{B1} across R and R1 is measured. The R.F. detector is then plugged into a suitable RF source and the output adjusted until the meter reads say 80 divisions. Next the bridge is rebalanced by adjustment of VR3 and the new value E_{B2} of the voltage across R and R1 is measured. The D.C. power change is then calculated as $dW = \frac{E^2_{B1} - E^2_{B2}}{4R1}$.

The zero set resistance VR3 is then readjusted to make the meter read 80 divisions again, and VR2 is adjusted so that the meter reads power as calculated. Thereafter direct power readings may be taken from the meter.

Alternatively or additionally, the bridge may be calibrated by measuring H.F. power from a known or standard source.

Having now particularly described and ascertained the nature of our said invention and in what manner the same is to be performed, we declare that what we claim is:—

1. A high-frequency current detector comprising two similar non-linear resistance elements connected in parallel across a co-axial line for high-frequency energy and in series in a D.C. or low-frequency circuit.

2. In or for a high-frequency current detector circuit an assembly comprising two non-linear resistance elements in conductive series connection between capacitatively-coupled parts of the outer conductor of a section of co-axial transmission line, the junction between the elements being connected to the inner conductor of said line section.

3. A high-frequency current detector according to Claim 1 or 2, wherein the resistance elements are thermistor beads.

4. A high-frequency wattmeter comprising a D.C. or relatively low-frequency bridge circuit one arm of which is constituted by two frequency-independent non-linear resistance elements in

series, said elements being arranged to be fed in parallel with H.F. energy by means of a co-axial line.

5. A high-frequency wattmeter according to claim 4 wherein the resistance elements are similar thermistor beads.

6. A high-frequency wattmeter according to claim 4 or 5 with compensation for change in ambient temperature substantially as described with reference to Fig. 4 of the accompanying drawings.

7. A high-frequency detector according to claim 1 substantially as described with reference to Fig. 5 of the accompanying drawings.

Dated this 13th day of December, 1945.

T. BROWN,
Chartered Patent Agent,
Agent for the Applicants.

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Published at The Patent Office, 25, Southampton Buildings, London, W.C.2, from which copies, price 1s. 0d. each (inland) 1s. 1d. (abroad) may be obtained.

[This Drawing is a reproduction of the Original on a reduced scale.]

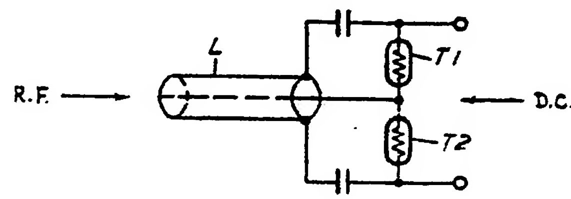


FIG. 1.

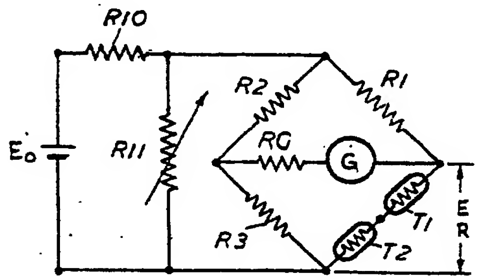


FIG. 2.

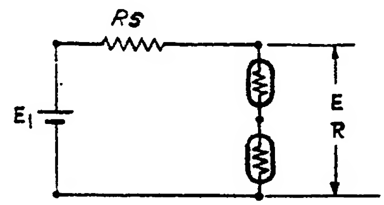


FIG. 2A

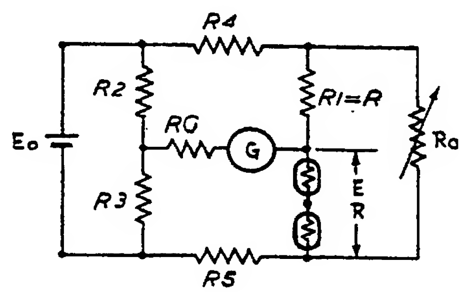


FIG. 3

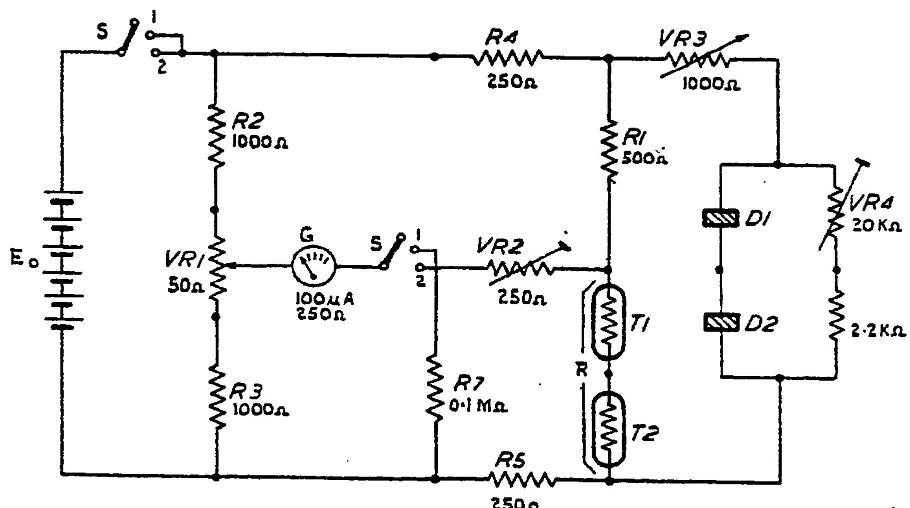
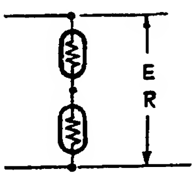


FIG. 4

.I.



IG. 2A

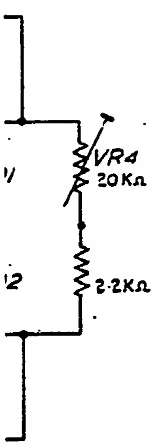


FIG. 4

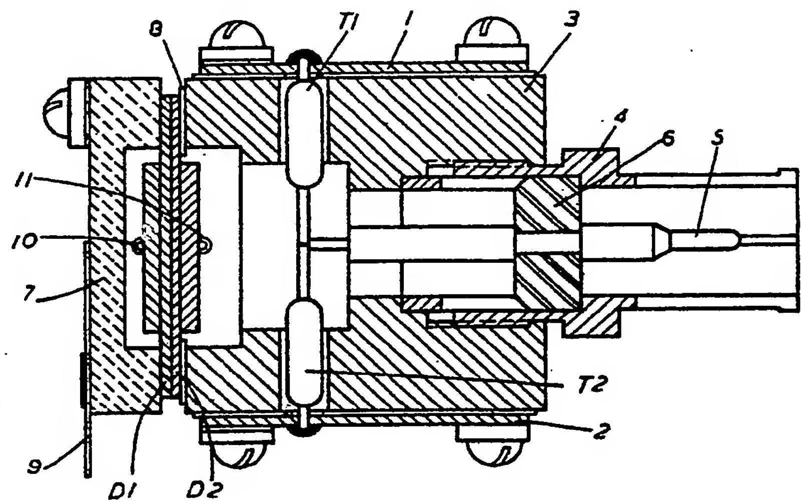


FIG. 5.

H.M.S.O.(Ty.P.)

605,734 COMPLETE SPECIFICATION

2 SHEETS

SHEET 1

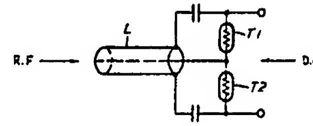


FIG. 1

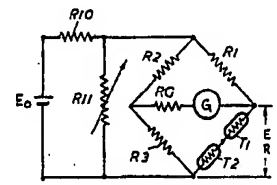


FIG. 2.

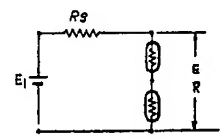


FIG. 2A

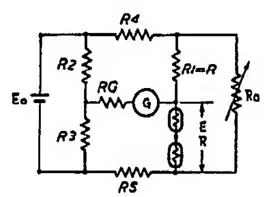


FIG. 3

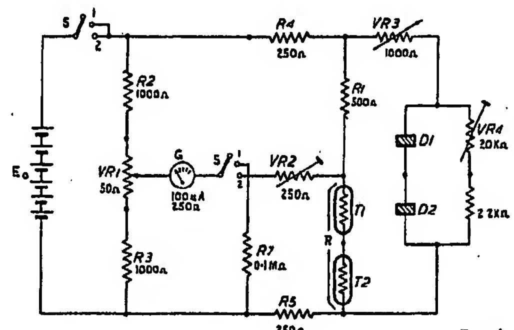


FIG. 4

SHEET 2

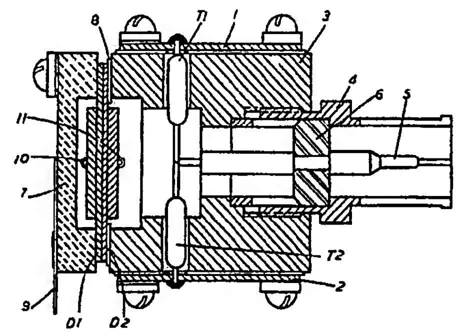


FIG. 5

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H.M.S.O.(Ty.P.)